Real Time Programming

(language support 1)

Sequential Programming is ”easy”

- No essential difference between algorithms and programs
- To describe algorithms as programs, a large number of programming languages available e.g. FORTRAN, C, C++, Java, Basic, PL1, Pascal, Algol60 ...
- A program is basically a function
  - From Input to Output
  - A sequence of operations on data structures

Typical structure of sequential programs

Program Foo(...)

Declaration 1 ←----- to introduce identities/variables
and define data structures

Declaration 2 ←----- to define ”operations” : procedures and functions
to manopulate the data structures

Main program
(Program body) ←------ a sequence of statements or ”operations” to
compute the result (output)

Why Concurrent programming ?

- Problem decomposition
  - Each task solves one sub-problem
- Structuring or abstraction (in many cases, it is so)
  - Many problems contain a set of sub-problems
  - It is just natural to solve/run them ”independently”/concurrently
  - In theory, you may solve all problems ”sequentially”
- Embedded systems: concurrent activities are everywhere (true concurrency/physical parallelism)

Concurrent programming

- A concurrent program is a collection of sequential programs running in parrallel, multi-thread on
  - single processor or
  - multiple processors
- The sequential parts here are often called a ”task”, ”thread”, or ”process”

  P1 || P2 || ... || Pn
- Nowadays, most programming languages support concurrency e.g. Ada, Concurrent Pascal, OO’s like Java, Simula, Modula 2, SR ... ...

Why is it so difficult to get ”concurrent programs” correct?

- The tasks may communicate with
  - each other or the ”environment”
- The tasks may share the same resources
  - E.g. Processor, memory etc
- The tasks may share ”data” (e.g. global variables)
  - May be seen as ”shared resources”
- It is much more difficult to debug and test!
  - Test all possible interleaing behaiour?
  - Test all possible time points?

Real time programming

- It is mostly about ”Concurrent programming”
- But not enough, we also need to handle Timing behaviour of concurrent programs/executions
- ”timing constraints” on concurrent executions are the outmost important part of real time programming

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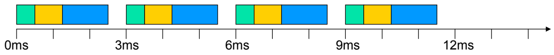
Cyclic Execution: the classic approach

the first example of real time programming without ”concurrency”

Static cyclic scheduling: example

Task	Required sample rate	Processing time
t1	3ms (333Hz)	0.5ms
t2	6ms (166Hz)	0.75ms
t3	14ms (71Hz)	1.25ms

```
void main(void)
{
    do_init();
    while (1)
    {
        t1();
        t2();
        t3();
        delay_until_cycle_start();
    }
}
```



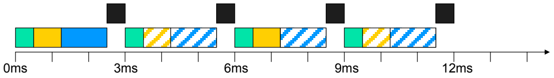
Cyclic scheduling: ”overheads”

Task	Required sample rate	Processing time
t1	3ms (333Hz)	0.5ms
t2	6ms (166Hz)	0.75ms
t3	14ms (71Hz)	1.25ms

t2 requires 12.5% CPU (0.75/6), uses 25% (4*0.75/12)

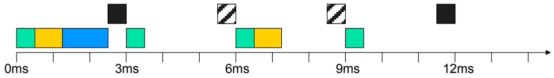
t3 requires 9% CPU (1.25/14), uses 42% (4*1.25/12)

add interrupt I with 0.5ms processing time



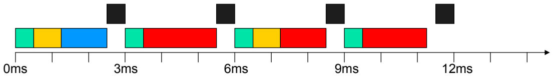
Major/minor cyclic scheduling

- 12ms major cycle containing 3ms minor cycles
  - t1 every 3ms, t2 every 6ms, t3 every 12ms
- t3 still upsampled (10.4% where 9% needed)
- time is still allocated for I every task in every cycle
  - will not always be used, but must be allowed for

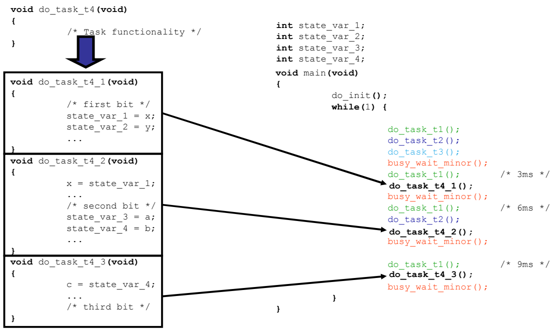


Fitting tasks to cycles

- add t4 with 14ms rate and 5ms processing time
- 12ms cycle has 5.25ms free time...
- ...but t4 has to be artificially partitioned



Effect of new task at code level



```
void do_task_t4(void)
{
        /* Task functionality */
}
```

```
void do_task_t4_1(void)
{
        /* first bit */
        state_var_1 = x;
        state_var_2 = y;
        ...
}
void do_task_t4_2(void)
{
        x = state_var_1;
        ...
        /* second bit */
        state_var_3 = a;
        state_var_4 = b;
        ...
}
void do_task_t4_3(void)
{
        c = state_var_4;
        ...
        /* third bit */
}
```

```
int state_var_1;
int state_var_2;
int state_var_3;
int state_var_4;
void main(void)
{
        do_init();
        while(1) {

                do_task_t1();
                do_task_t2();
                do_task_t3();
                busy_wait_minor();
                do_task_t1();           /* 3ms */
                do_task_t4_1();
                busy_wait_minor();
                do_task_t1();           /* 6ms */
                do_task_t2();
                do_task_t4_2();
                busy_wait_minor();

                do_task_t1();           /* 9ms */
                do_task_t4_3();
                busy_wait_minor();
        }
}
```

This is too ”ad hoc”, though this is often used in industry

- You just don’t want to do this for large software systems, say a few hundreds of control tasks

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Concurrent Programming

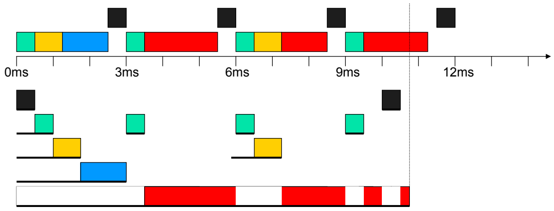
Concurrent programming:
using sequential programming languages

- Program your computation tasks, execute them concurrently with OS support e.g. in LegOS

execi(foo1, ..., priority1, ...);
execi(foo2, ..., priority2, ...);
execi(foo3, ..., priority3, ...);

Will start three concurrent tasks running foo1, foo2, foo3

Cyclic vs. Concurrent



Programming Languages for concurrent (and real time) programming

Let’s look at Ada95

Note that there is no reason why you can’t program a real time system using C. But there is no language support for concurrent tasks and real time features, so you would have to provide them yourself using e.g. exec(), sleep(20) etc, and most importantly, you would have to fix scheduling

Ada95

- It is strongly typed OO language, looks like Pascal
- Originally designed by the US DoD as a language for large safety critical systems i.e. Military systems
  - Ada83
  - Ada95 + RT annex + Distributed Systems Annex
  - Ada 2005

The basic structures in Ada

- A large part in common with other languages
  - Procedures
  - Functions
  - Basic types: integers, characters, ...
  - Control statements: if, for, ..., case analysis
- Abstract data type: Packages
- Protected data type
- Tasking: concurrency
- Task communication: rendezvous
- Real Time

Declarations and statements

- Before each block, you have to declare (define) the variables used, just like any sequential program

```
procedure PM (A : in  INTEGER;
               B:  in out  INTEGER;
                C : out     INTEGER) is
begin
     B := B+A;
     C := B + A;
end PM;
```

If, for, case: contrl-statements

```
if TEMP < 15 then
     some smart code;
else
 do something else..;
end if;

case TAL is
     when <2 =>
          PUT_LINE(”one or two”);
     when >4 =>
          PUT_LINE(”greater than 4);
end case;

for I in 1..12 loop
     PUT(”in the loop”);
end loop;
```

Types (like in Pascal or any other fancy languages)

```
type LINE_NUMBER is range 1 .. 72
type WEEKDAY is (Monday, Tuesday, Wednesday);
type serie is array (1..10) of FLOAT;

type CAR is
     record
          REG_NUMBER     : STRING(1 .. 6);
          TYPE             : STRING(1 .. 20);
     end record;
```

Anything new in Ada?

Concurrent (and Real Time) Programming with Ada

- Abstract data types: packages & protected data types
  - Consistent data sharing
- Concurrency: multi-tasking
- Task communication: Rendezvous & Shared Variables
- Real time:
  - Delay constructs e.g. Delay(10), Delay until next-time
  - Scheduling according to timing constraints

”Package”: abstract data type in Ada

- package definition ---- specification
- packagebody ---- implementation

Package definition

- Objects declared in specification is visible externally.

```
package MY_PACKAGE is
    procedure myfirst_procedure;
    procedure mysecond_procedure;
end MY_PACKAGE;
```

Packagebody

- Implements package specification

```
(you probably want to use some other packages here e.g.. )
with TEXT_IO;
use TEXT_IO;

 package body MY_PACKAGE is
            procedure myfirst_procedure is
            begin
                        myfirst_procedure code here;
            end;

            function MAX (X,Y :INTEGER) return INTEGER is
            begin
              … …
            end;

            procedure mysecond_procedure is
            begin
                        PUT_LINE("Hello Im Ada Who are U");
                        GET();
            end;
end MY_PACKAGE;
```

Protected data type

```
protected x is
procedure read(x: out integer)
procedure write(x: in integer)
private
   v: integer := 0  /* initial value */
protected body x is
procedure read(x: out integer) is
begin x:=v end
procedure write(x: in integer) is
begin v:= x end
```

You may solve the problem with semaphores!

Ada tasking: concurrent programming

- Ada provides at the language level light-weight tasks. These often refered to as threads in some other languages. The basic form is:

```
task T is                      <-------- specification
--- operations/entry or nothing
end T;

task body T is                 <--------- implementation/body
begin
---- processing----
end T;
```

Example: the sequential case

```
procedure shopping is
begin
buy-meat;
buy-salad;
buy-wine;
end
```

The concurrent version

```
procedure shopping is

task get-salad;
task body get-salad is
begin
buy-salad;
end  get-salad;
task get-wine;
task body get-wine is
begin
buy-wine;
end  get-wine;
begin
buy-meat;
end
```

buy-salad and buy-wine will be activated concurrently here

And then run in parallel with buy-meat

Creating Tasks

- A sequential process is called a Task in Ada
- Tasks may be declared at any program level
- Created implicitly upon entry to the scope of their declaration.
- Possible to declare task types to start several task instances of the same task type

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example

```
procedure Example1 is
    task type A_Type;
    task B;
    A,C : A_Type;

    task body A_Type is
            --local declarations for task A and C
    begin
            --sequence of statements for task A and C
    end A_Type;

    task body B is
            --local declarations for task B
    begin
            --sequence of statements for task B
    end B;

begin
    --task A,C and B start their executions before the first statement of this procedure.
end Example1;
```

Task communication: two methods

- Message passing using ”rendezvous”
  - entry and accept
- Shared variables
  - protected objects/variables

Rendezvous

```
procedure foo

        task T is
         entry E(...in/out parameter...);
        end;
        task body T is
         begin
               -------
         accept E(... ...) do
               ------- sequence of statements
         end E;

         task user;
         task body user is
         begin
         ---
         T.E(... ...)
         ---
         end
begin
...
end

end foo;
```

T and user will be started concurrently

Rendezvous

```
task body A is
begin
...
B.Call;
...
end A
```

```
task body B is
begin
...
accept Call do
....
end Call
...
end A
```

Buffer

```
task buffer is
entry put(X: in integer)
entry get(x: out integer)
end;

task body buffer is
  v: integer;
 begin
 loop accept put(x: in integer) do v:= x end put;
        accpet get(x: out integer) do x:= v end get;
 end loop;
 end buffer;

---
buffer.put(...)        <--------------------------------------------- other tasks (users)!!
buffer get(...)
----
```

Choice: Select statement (choices)

```
task Server is
      entry S1(...);
      entry S2(...);
end Server;

task body Server is
      ...
begin
      loop
            --prepare for service
            select
               when <boolean expression> =>
                  accept S1(...) do
                        --code for this service
                  end S1;
            or
                  accept S2(...) do
                        --code for this service
                  end S2;
            or
                  terminate;
            end select;
      --do any house keeping
      end loop;
end Server;
```

Timeout and message passing

```
loop
    select
          accept Call(T : temperature) do
                    New_temp:=T;
          end Call;
    or
          delay 10.0;
                    --action for timeout
    end select;
    --other actions
end loop;
```

This is implemented with Entry queues (the compiler takes care of this!)

- Each task has a queue
- A call to a task entry is inserted in the queue
- The queue is a simple FIFO without priority
- A task in an entry queue is inactive (waiting)
- The first task in the queue will be ”accepted” first (like the queue for a semaphore)

Conditional/Timed entry call

```
loop
    --get temperature
    select
           Controller.Call(T);      -- put new temperature
    or
          delay 0.5
         --other actions
    end select;
end loop;
```

Clocks

- Provided by predefined library package (Calendar) and an optional real-time facility.
    - Abstract datatype Time
    - Time provides a function Clock for reading the time
- Primitive type Duration provided for time calculations.

Periodic task

```
task body Periodic_T is
    Next_Release : Time;
    ReleaseInterval : Duration := 10
begin
    Next_Release := Clock  + ReleaseInterval;
    loop
          --sample data and calculations
          delay until Next_Release;
          Next_Release := Next_Release +
    ReleaseInterval;
    end loop;
```

Task scheduling

- Allow priorities to be assigned to tasks in task definition
- Allow task dispatching policy to be set (Default: highest priority first)

```
task Controller is
      pragma Priority(10)
end Controller
```

Task termination

- A task in Ada will terminate if:
    - It completes execution of its body
    - It executes a terminate alternative of a select statement
    - It is aborted